

### 3.0 DOCUMENTATION

Information used to prepare this Technical Memorandum includes site-specific data and reports, and technical literature.

#### 3.1 Site-Specific Documentation and Data

The following site-specific documentation and data set forth in the approved work plan were considered during the preparation of this Technical Memorandum:

- *Wells G&H Site Central Area Remedial Investigation, Phase 1A Report.* Prepared for: Beatrice Corporation, UniFirst Corporation, W.R. Grace & Co. – Conn. Prepared by: GeoTrans, Inc. and RETEC. February 14, 1994.
- *Piezcone Mapping, Groundwater Monitoring, and Flow Modeling in a Riverine Peatland: Implications for the Transport of Arsenic.* Submitted to the Department of Civil and Environmental Engineering in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Civil and Environmental Engineering at the Massachusetts Institute of Technology. Prepared by Peter John Zeeb. August 1996
- Technical papers by lead author Helena Solo-Gabriele, Ph.D.:
  - Solo-Gabriele, H.M. and F.E. Perkins, *Watershed-Specific Model for Streamflow, Sediment, and Metal Transport*, Journal of Environmental Engineering, January 1997,
  - Solo-Gabriele, H.M. and F.E. Perkins, *Metal Transport within a Small Urbanized Watershed*, Journal of Irrigation and Drainage Engineering, March-April 1997.
  - Solo-Gabriele, H.M. and F.E. Perkins, *Streamflow and Suspended Sediment Transport in an Urban Environment*, Journal of Hydraulic Engineering, September 1997.
  - Solo-Gabriele, H.M., *Generation of Long-Term Record of Contaminant Transport*, Journal of Environmental Engineering, July 1998.
- Historical land use data as described in the following documents prepared by the Woburn Redevelopment Authority (WRA):
  - Wells G&H Superfund Redevelopment Initiative. Advisory Committee Information Package. April 24, 2002.
  - Wells G&H Superfund Redevelopment Initiative. Advisory Committee Information Package. June 5, 2002.
  - Wells G&H Superfund Redevelopment Initiative. Advisory Committee Information Package. September 4, 2002.

- TRC Central Area Groundwater Analytical Data. October 2002.
- *Data Summary Report for the Former Drum Disposal Area, Wells G&H Superfund Site, Operable Unit 1 – Olympia Property, Woburn, Massachusetts.* Prepared for the United States Environmental Protection Agency. Prepared by TRC Environmental Corporation. December 2002.
- *Baseline Human Health and Ecological Risk Assessment Report, Wells G&H Superfund Site, Aberjona River Study, Operable Unit 3, Woburn, Massachusetts.* Prepared for the United States Environmental Protection Agency. Prepared by Metcalf & Eddy, Inc., September 2004.
- TTNUS Aberjona River Base and Storm Flow Surface Water Data May 2001 – October 2002.
- *Draft Preliminary MSGRP Supplemental Report, Southern Area, Remedial Investigation/ Feasibility Study, Industri-Plex Site, Woburn, Massachusetts.* Prepared for the United States Environmental Protection Agency. Prepared by TetraTech NUS, Inc. June 2003.
- *Final Project Report, Natural Attenuation Study, Groundwater, Surface Water, Soil and Sediment Investigation, Industri-Plex Superfund Site, Woburn, Massachusetts.* Prepared by Robert Ford, United States Environmental Protection Agency, Office of Research and Development, National Risk Management Research Laboratory, Subsurface Protection and Remediation Division, Subsurface Remediation Branch. September 2, 2004.
- Historical groundwater data from the City of Woburn during the operation of municipal water supply wells G & H (various dates).
- Wells G & H source area monitoring data (contained in annual operation and maintenance reports, various dates).

A summary of each of these documents is provided below:

### **3.1.1 Wells G&H Site Central Area Remedial Investigation, Phase 1A Report (GeoTrans, 1994)**

GeoTrans (1994) prepared the *Wells G&H Site Central Area Remedial Investigation, Phase 1A Report* (Phase 1A) on behalf of W.R. Grace & Co. – Conn (Grace), UniFirst Corporation (UniFirst), and Beatrice Corporation (Beatrice) pursuant to the September 21, 1990 Consent Decree between the PRPs and EPA. The report presents a description and discussion regarding the Central Area (OU-2) of the Wells G and H Site. The GeoTrans (1994) conceptual model of the Aberjona River watershed describes the hydrogeologic conditions that affect groundwater flow and chemical transport in the Central Area (OU-2); the interactions of the Aberjona River and the Central Area aquifer; the nature and extent of contamination in the Central Area; and past, present, and likely future sources of contamination.

The Phase IA effort included the installation of 188 monitoring wells, the collection of 728 groundwater and surface water samples, and 492 groundwater level measurements. Groundwater monitoring data from the monitoring well network were collected over an approximately 23 year period. Some of the data are validated. Some of the metals groundwater data were collected using low-flow procedures; however, earlier data from the 1980s and some from the early 1990s were not collected by low-flow procedures. The suite of metals analysis, however, is limited and includes only arsenic, lead, and chromium. Other inorganic analytes include chloride, sulfate, and nitrate.

GeoTrans asserted that the hydraulic connection between the Central Area aquifer and the Aberjona River resulted in the induced infiltration of contaminated Aberjona River surface water into the underlying Central Area aquifer in response to pumping of Wells G and H. GeoTrans also stated that under current hydraulic conditions (no groundwater withdrawal by the municipal wells), there is a natural groundwater discharge of approximately 450 gallons per minute (gpm) from the Central Area aquifer to the Aberjona River and associated wetlands, which GeoTrans expects to result in a natural extraction, or natural flushing of contaminated groundwater from the Central Area aquifer.

GeoTrans noted Central Area aquifer exceedances of drinking water standards and guidelines for a variety of chemicals and compounds including inorganic and organic compounds such as arsenic, beryllium, chromium, cadmium, lead, nitrate, benzene, toluene, tetrachloroethene, trichloroethene, and vinyl chloride. GeoTrans ascribed the contamination to a wide variety of sources other than the sources identified in the ROD, and claimed that it was not possible to define or map individual contaminant plumes for any significant distance due to the pervasive and widespread contamination. Nonetheless, GeoTrans described indications of previously undetected additional contaminant sources in the watershed. GeoTrans concluded that restoration of the Central Area aquifer was technically impracticable and additional investigation and evaluation was unwarranted (GeoTrans, 1994).

### ***3.1.2 Piezocone Mapping, Groundwater Monitoring, and Flow Modeling in a Riverine Peatland: Implications for the Transport of Arsenic (Zeeb, 1996)***

Zeeb (1996) evaluated the influence of deposit-scale features of a contaminated riverine wetland on the interaction between surface water and wetland groundwater, with a focus on the fate of riverborne arsenic in the wetland.

Zeeb conducted detailed stratigraphic mapping of the wetland that separates the Aberjona River at its closest approach to Well H using a wetland piezocone penetrometer. The mapping revealed an ice-block depression filled with silt overlain by several distinct peat strata and sand layers. The post-glacial history follows a progression from fresh water lacustrine deposition, to woody swamp, to sedge meadow, to cattail marsh. Zeeb determined that the distribution of arsenic in the soil profile suggested that arsenic was deposited on the former wetland surface in a sedimentary form, some of which was transported to depth in groundwater.

Zeeb (1996) indicated that the arsenic contained in a small sand layer in the shallow peat is relatively mobile, but suggested that the arsenic contained in streambed sediments could serve as

a source of arsenic to the outside wetland if the layers were extensive enough. Zeeb postulated that in areas of the river where the peat layer was thin, river water could have supplied Wells G and H, but in his study area the amount of peat water that could drain to Wells G and H would have been small based on Zeeb's study results.

### ***3.1.3 Four Technical Papers by Lead Author Helena Solo-Gabriele, Ph.D. (Solo-Gabriele, 1997 a,b,c, 1998)***

The four technical papers were based on the data and findings from Solo-Gabriele (1995) and describe the use of hydrograph separation techniques to interpret metals data in the Aberjona watershed. The metals include iron, chromium, copper and the metalloid arsenic. The river system was modeled as a series of box models to evaluate macro-scale effects of stream flow components and associated sediment transport characteristics on metal transport. The bulk effects of various water sources were characterized by different response times, and the timing was based on hydrographs.

Three major flow components were identified and characterized (quick storm flow, slow storm flow, and long-term baseflow). The geographic distribution of metals inputs was examined, with metals concentrations highest in the upper reaches of the Aberjona River and an overall decrease in the downstream direction. Total metal concentrations were higher during storm conditions compared to low flow situations. During storm events, particulate metal concentrations increased significantly above typical concentrations observed during low flows. Concentrations for all metals exhibited a strong flushing effect with bursts of particulate metal transport at the initiation of storm flow conditions (Solo-Gabriele and Perkins, 1997 a, b, and c). Retrospective modeling of the river showed that 72-percent of the arsenic was transported during low flow conditions, as opposed to 31-percent of the chromium. Most chromium (80-percent) was transported in the particulate phase, whereas arsenic was roughly equally distributed between dissolved and particulate phases (Solo-Gabriele, 1998).

### ***3.1.4 Wells G and H Superfund Redevelopment Initiative Information Packages (WRA, 2002 a,b,c)***

In July 13, 2000, EPA announced that five Superfund sites in Massachusetts, including the Wells G&H Site, would receive federal grants to help the recipient community plan for the productive use of a toxic waste site. The EPA Superfund Redevelopment Initiative was intended as an aggressive planning tool to encourage community decisions on the future use of abandoned and contaminated properties.

The City of Woburn, through the WRA is employing the funding to develop a reuse plan to evaluate reasonable future uses for the municipal parcels and adjacent properties now affected by contamination from the Wells G and H site. The City of Woburn involves the community and other stakeholders in deciding how to reuse the property, including developing a land use plan and participating in city-sponsored and EPA public meetings.

The three Wells G and H Superfund Redevelopment Initiative Information Packages (WRA, 2002 a,b,c) compiled meeting minutes, newspaper articles, and working papers (e.g., marketing

analyses, oil and hazardous waste release site reviews). The information packages include anecdotal information on past land use, discussions of zoning issues, and maps and figures illustrating proposed plans for properties in the Wells G and H Superfund site.

### ***3.1.5 TRC Central Area Well Data (TRC, 2002 b,c)***

In October, 2002, TRC sampled eight previously installed groundwater monitoring wells located in the Central Area of the Wells G and H Superfund Site to collect current information on the groundwater quality in the eastern portion of the Aberjona Aquifer and adjacent properties. Prior to this, chemical contaminant data from this area were last collected in the early 1990s. The wells sampled were: S-63S, S-68D, S-82, S-85S, S-86S, S-87D, S-89S, and UC-11.

Tetrachloroethene (PCE) was selected as a marker contaminant for the chlorinated volatile organic compound (VOC) plume in this area.

The wells were chosen to assess the orientation, magnitude and extent of the plume. Existing data showed the plume orientation was approximately southwest towards the Aberjona River at one time, but deflected more due south towards Wells G and H when they began pumping. TRC estimates that it likely took several years after pumping ceased for the plume to move off this alignment to its current position. However, once the wells were shut down, the plume appears to have realigned to a more southwest pattern.

All samples were analyzed for VOCs, SVOCs, metals, and cyanide. Two wells were analyzed for polychlorinated biphenyls (PCBs) and pesticides (TRC, 2002b). All samples were collected using EPA Region I low stress (low-flow) sampling protocols except for samples collected from well UC-11. Monitoring well UC-11 is a Waterloo-style multi-level well that requires special equipment for sample collection. The sample from UC-11 was collected by GeoTrans personnel for analysis by EPA. Arsenic was detected in seven out of eight wells. All arsenic detections were below the current EPA MCL of 10 micrograms per liter (ug/L) for arsenic.

### ***3.1.6 Data Summary Report for the Former Drum Disposal Area, Wells G&H Superfund Site, Operable Unit 1 – Olympia Property, Woburn, Massachusetts (TRC, 2002a)***

The TRC (2002a) Data Summary Report organized and evaluated data collected from the Pre-Design Investigation and Site Characterization at the Olympia Property Superfund Site in Woburn, Massachusetts. The evaluation summarized newly collected data, discussed trends, and compared the data to existing contaminant standards and guidelines and identified data gaps.

The Olympia Site is the location of a Former Drum Disposal Area (FDDA). Available documentation indicated 17 drums were disposed sometime prior to their discovery in 1979/1980. The primary objectives of this TRC study were to delineate the trichloroethene (TCE) plume, define the clay layer in the FDDA, define hydraulics of the aquifer and silt clay layer at the FDDA, update data on Central Area and Olympia Terminal groundwater contamination, verify FDDA surface soil contamination identified by others, and delineate residual contaminated soil in subsurface soil in the FDDA.

Arsenic was not identified as an FDDA contaminant in prior site reports; however, arsenic was detected in all FDDA soil samples and in all 62 monitoring wells sampled by TRC at concentrations in excess of one or more comparison criteria. The highest concentrations of arsenic in groundwater tended to be shallow and located in the central Aberjona River valley, including the Olympia Terminal property. In these areas, 13 wells exceeded the current EPA MCL of 10 ug/L for arsenic. In the FDDA one soil sample yielded an arsenic concentration greater than the MADEP background concentration of 20 milligrams per kilogram (mg/Kg) [MADEP, 2002].

### ***3.1.7 Baseline Human Health and Ecological Risk Assessment Report (Aberjona River Study) [M&E, 2004]***

M&E (2004) issued the Baseline Human Health and Ecological Risk Assessment for the Aberjona River Study Area. The baseline risk assessment for the Aberjona River Study Area focused on sediments and soils along six miles of the Aberjona River and wetlands from Route 128 in Woburn to the Mystic Lakes in Arlington and Medford. The study area was divided into six sections, or reaches along the river. Reach 1 contains the Wells G and H Superfund Site and associated 38-acre wetland. Reach 2 contains a former cranberry bog to the south. After the cranberry bog, the river continues to flow south as a well-defined river channel through Reaches 3, 4 and 5 prior to discharging into Reach 6, the Mystic Lakes (EPA, 2003a).

The M&E study was based on analysis of over 390 sediment and soil samples from 52 sampling stations along the study area. Additional sediment samples were collected from 12 stations outside the study area to provide background information for comparison. Surface water and fish samples were collected from inside and outside the study area. EPA conducted various studies to more accurately characterize potential risks along the study area (EPA, 2003a).

Arsenic was present in sediments throughout the study area. Other metals, including antimony, chromium, copper, lead, mercury and zinc, were also detected at elevated levels. The Wells G and H 38-acre wetland exhibited some of the highest concentrations of metals within the study area (EPA, 2003a).

M&E concluded that sediments may pose a current health risk to people using the study area in two exposure areas along the east side of the Wells G and H 38-acre wetland (near the former municipal Well H), and in the irrigation channels along the western side of the center of the 17-acre former cranberry bog located to the south of Salem Street. Six other exposure areas evaluated for potential risks along the former cranberry bog showed no health risk (EPA, 2003b).

The ecological risk assessment did not reveal a risk to fish or green heron within the study area. However, risks were widely observed from depositional sediments in the Wells G and H 38-acre wetland and in the 17-acre former cranberry bog. Two sediment locations in the Mystic Lakes indicated potential risks to benthic invertebrates. The risks were primarily due to exposure to metals contamination in sediments and/or vegetation growing in contaminated sediments.

### **3.1.8 TTNUS Aberjona River Base and Storm Flow Surface Water Data May 2001 – October 2002 (TTNUS, 2002)**

TTNUS collected data over an 18-month period from May 2001 to October 2002. Data collected included precipitation measurements, stream flow, total suspended solids (TSS), metals (total and dissolved), and select physico-chemical parameters (i.e., temperature, specific conductivity, dissolved oxygen [DO], potential of hydrogen [pH], oxidation reduction potential [ORP], and turbidity). Metals analysis included arsenic, iron, chromium, copper, lead, and mercury.

TTNUS observed that TSS impacts metals transport in surface water, since spikes in metals concentrations were often associated with spikes in TSS. Unique TSS behavior was observed at Station 4 (the discharge control structure for the Hall's Brook Holding Area [HBHA] at Mishawum Road).

TTNUS observed that arsenic concentrations, as well as the concentrations of other metals, tended to be higher in the northern portion of the river and near the Industri-Plex Superfund Site, with the highest concentrations generally observed at Station 2 and Station 4. TTNUS estimated that 80 to 90-percent of the arsenic in the Aberjona River originates from north of Route 128 and near Industri-Plex. Total metal concentrations typically decreased downstream of the HBHA outfall, with the most significant reductions being observed in the particulate phase.

TTNUS observed iron as the highest concentration metal during baseflow, with the highest iron concentrations observed in the HBHA outfall. TTNUS observed an apparent direct relationship between arsenic and iron concentrations in both the total and dissolved phases, but found no clear relationship between total metals concentrations and river flow rate.

The following table summarizes average contaminant and water quality data ranges during base flow from the 18-month TTNUS sampling program from Station 4 (the HBHA outflow north of Wells G and H and Station 5 (at the Salem Street bridge south of Wells G and H). These stations are representative of river water passing through the Wells G and H Central Area wetland.

<b>Base Flow River Contaminant/Water Quality Monitoring Data</b>												
<b>Station</b>	<b>Arsenic</b>		<b>Iron</b>		<b>Chromium</b>		<b>Copper</b>		<b>Lead</b>		<b>Mercury</b>	
	<b>Dis</b>	<b>Tot</b>	<b>Dis</b>	<b>Tot</b>	<b>Dis</b>	<b>Tot</b>	<b>Dis</b>	<b>Tot</b>	<b>Dis</b>	<b>Tot</b>	<b>Dis</b>	<b>Tot</b>
<b>4</b>	5.95	37.1	487	5,270	1.07	11.5	2.4	17.4	0.80	7.87	0.05	0.08
<b>5</b>	6.04	20.3	550	2,430	1.33	7.2	1.77	5.36	0.85	3.45	0.05	0.06

Water Quality Data (units as indicated)						
Station	Water Temp (°C)	Specific Conductivity (µg/cm)	Dissolved Oxygen (mg/L)	pH (Standard Units)	ORP (mV)	Turbidity (NTUs)
4	2.6 to 25.0	388 to 959	3.2 to 11.8	6.7 to 7.28	+184 to +440	10 to 294
5	2.4 to 24.4	454 to 1,079	4.2 to 11.8	6.53 to 7.05	+170 to +485	3.9 to 434

**Notes:**

Dis = Dissolved (filtered)

Tot = Total (unfiltered)

µg/L = micrograms per liter

°C = degrees Celsius

mg/L = milligrams per liter

mV = millivolts

NTUs = nephelometric turbidity units

The above-tabulated data from the TTNUS study demonstrate that dissolved metals concentrations are generally low in the reach of the Aberjona River passing Wells G and H. In addition, the water quality data demonstrate that the Wells G and H reach of the river is in a constant state of oxidation and oxygen enrichment.

**3.1.9 Draft Preliminary MSGRP Supplemental Report, Southern Area, Remedial Investigation/ Feasibility Study, Industri-Plex Site, Woburn, Massachusetts (TTNUS, 2003)**

TTNUS (2003) prepared this report to support the EPA's Multiple Source Groundwater Response Plan (MSGRP) investigations prescribed under the ROD for the Industri-Plex Superfund Site. TTNUS researched existing information on other potential source areas and evaluated their potential to impact the surface water and sediment quality of the Aberjona River.

To describe local hydrogeology, TTNUS summarized the findings of others (e.g., United States Geological Survey [USGS]) that report the tendency for groundwater to discharge to the Aberjona River through highly transmissive and unconfined stratified drift aquifer materials. The stream bed of the Aberjona River was described as leaky. Between rain events, water is primarily supplied to the Aberjona River by groundwater. TTNUS also noted that groundwater flow towards the river is reversed when the river stage rapidly increases, although the reversal effect is temporary, localized, and does not involve large volumes of water. [Although not identified in the TTNUS report, a similar localized groundwater flow reversal was noted by The RETEC Group, Inc. (RETEC) at the Wildwood Conservation Corporation (Wildwood) and Aberjona Autoparts properties, which was attributed to periodic high water conditions in the Aberjona River. Beaver dams on the river were also cited by RETEC as a contributing factor to high water conditions near these properties (RETEC, 2003).]

TTNUS identified several potential historical sources of arsenic in proximity to municipal Wells G and H and the 38-acre wetland, including agricultural operations northeast of Well H, former orchards at 200 Wildwood Avenue and at 399 Washington Street, and a greenhouse on



Washington Street. The TTNUS review noted the presence of arsenic in soil at the Wildwood property (60.7 mg/kg), discovery of numerous containers of arsenic trioxide on the Olympia property, and the presence of tannery wastes at properties occupying parts of the former John J. Riley Tannery property. Some of the properties on the subdivided John J. Riley (Riley) Tannery parcel have achieved a Response Action Outcome (RAO) under the Massachusetts Contingency Plan (MCP; 310 CMR 40.0000); however, some still have tannery wastes in place that could serve as a continuing source of contamination, particularly chromium.

Potential non-point sources identified in the TTNUS report included sewer overflows, municipal pesticide usage (gypsy moth spraying), roadway runoff and runoff from developed areas, and fertilizer applications, and the use of monosodium methane arsenate (MSMA) as an herbicide along the Boston and Maine railroad tracks.

***3.1.10 Final Project Report, Natural Attenuation Study, Groundwater, Surface Water, Soil and Sediment Investigation, Industri-Plex Superfund Site, Woburn, Massachusetts (Ford, 2004b)***

Ford (2004b) provides an assessment of arsenic contamination within the Industri-Plex Superfund Site and Groundwater/Surface Water Investigation Plan (GSIP) Study Area. The purposes of this study were to:

1. Determine the migration mechanisms controlling arsenic transport at the Industri-Plex Superfund Site and the GSIP Study Area;
2. Provide an evaluation of the potential role of natural attenuation processes in mitigating arsenic transport from the Industri-Plex Superfund Site and GSIP Study Area; and
3. Provide guidance for determination of reasonable, cost effective treatment technologies for a river/wetland in an urban watershed. The information derived from this report will be incorporated into the Industri-Plex Superfund Site, Operable Unit 2 (OU-2), MSGRP, and Remedial Investigation/Feasibility Study (RI/FS).

Ford investigated the migration of arsenic from suspected source areas within the Industri-Plex Superfund Site into the HBHA. Three goals were addressed as part of this investigation:

1. Identification of the mobile form of arsenic in groundwater;
2. Identification of the processes controlling arsenic uptake onto HBHA sediments; and
3. Evaluation of the stability of arsenic associated with HBHA sediments. This information serves as a basis for identifying the effectiveness of natural attenuation within the HBHA to mitigate downgradient migration of arsenic into the Aberjona River and for evaluation of potential remedial alternatives.

Ford (2004b) also documented the collection of sediments in the HBHA wetland and Wells G and H 38 acre wetland, including one sample collected near Well H (sediment sample GHME12B). The sediment samples were collected to assess the distribution and stability of

sediment-associated arsenic downgradient of the HBHA Pond. Select geochemical parameters and dissolved metals were analyzed on sediment pore water isolated from the sediment samples. In addition, subsamples of dried sediment were subjected to oxic leaching tests to assess arsenic release under oxic conditions.

Ford found that sediment pore waters contained elevated concentrations of arsenic ranging from approximately 160 to 670 ug/L, which did not correlate directly with the sediment arsenic concentration for all sediments. Following removal of the major portion of pore water, the sediments were dried and then analyzed for total element concentrations.

During oxic leaching tests of the sediments, uncontaminated, oxygenated, water was allowed to equilibrate with the dried sediments and the water quality was monitored over time to determine arsenic concentration. Measurements of the oxidation-reduction potential showed that sediment suspensions become more oxidizing over time. In all cases, most of the leached arsenic had been released within a 30-minute reaction period. Sediment samples GHME12B and GH2801 from the Wells G and H wetland showed the greatest arsenic release with average leachable concentrations of 341 ug/L (standard deviation 27 ug/L) and 112 ug/L (standard deviation 42 ug/L) respectively over a 4-hour period. The arsenic mass released per unit weight of sediment was 24 µg/g (standard deviation 1 µg/g) and 3 µg/g (standard deviation 1 µg/g) for GHME12B and GH2801, respectively. Arsenic release was less for sediment samples GH2901 (from the Wells G and H wetland south of Well H) and HBHAW02B (from the HBHA) with concentrations of 23 ug/L and 12 ug/L, respectively.

The batch test may not represent a continuous flow system in which the desorbed arsenic is continuously eluted from the reaction zone. Also, the batch tests do not capture the conditions that may be induced by microbial activity that could occur under induced infiltration (Ford, 2005a).

### ***3.1.11 Historical City of Woburn Data from Municipal Water Supply Wells G & H (Various Dates)***

Historical City of Woburn analytical testing of water from municipal water supply wells G and H was obtained from data compiled by the Massachusetts Department of Environmental Protection (MADEP). None of the analytical data included arsenic. However, data for iron, manganese and other inorganic analytes were included. Organic chemical data, pumping rates, and some related operational data were also included.

### ***3.1.12 Wells G & H Source Area Monitoring Data***

Routine Wells G and H Source Area (OU-1) monitoring data were limited to VOCs. No metals data were provided from monitoring wells routinely monitored as part of Source Area (OU-1) remediation/compliance activities.

### 3.2 Additional Technical Literature

The following additional technical literature was considered in the preparation of this Technical Memorandum:

- *City of Woburn, Woburn, Massachusetts Report on East Side Water Problems – Wells G&H.* Prepared for Department of Public Works, Albert J. Wall, Superintendent. Prepared by Dufresne-Henry Engineering Corporation, North Springfield, Vermont. January 1978.
- Cherry, J.A., A.U. Shaikh, D.E. Tallman, and R.V. Nicholson. *Arsenic Species as an Indicator of Redox Conditions in Groundwater.* Journal of Hydrology, Volume 43, Pages 373 to 392, 1979.
- Pierce, M.L. and C.B. Moore. *Adsorption of Arsenite and Arsenate on Amorphous Iron Hydroxide.* Water Resources, Volume 16, Pages 1247 to 1253, 1982.
- Brannon, J.M. and W.H. Patrick, Jr., *Fixation, Transformation, and Mobilization of Arsenic in Sediments.* Environmental Science and Technology, Volume 21, Number 5, Pages 450 to 459, 1987.
- Moore, J.N., W.H. Ficklin, and C. Johns. *Partitioning of Arsenic and Metals in Reducing Sulfidic Sediments.* Environmental Science and Technology, Volume 22, Number 4, Pages 432 to 437, 1988.
- Masscheleyn, P.H., R.D. Delaune, and W.H. Patrick, Jr. *Arsenic and Selenium Chemistry as Affected by Sediment Redox Potential and pH.* Journal of Environmental Quality, Volume 20, Pages 522 to 527, 1991.
- Masscheleyn, P.H., R.D. Delaune, and W.H. Patrick, Jr. *Effect of Redox Potential and pH on Arsenic Speciation and Solubility in a Contaminated Soil.* Environmental Science and Technology, Volume 25, Number 8, Pages 1414 to 1419, 1991.
- Knox, M.L. *The Distribution and Depositional History of Metals in Surface Sediments of the Aberjona River Watershed.* Submitted to the Department of Civil and Environmental Engineering in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering at the Massachusetts Institute of Technology. September 1991.
- Aurilio, A.C. *Arsenic in the Aberjona Watershed.* Submitted to the Department of Civil and Environmental Engineering in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering at the Massachusetts Institute of Technology. September 1992.
- Bialon, J.L. *Characterization of the Physical and Engineering Properties of the Aberjona Wetland Sediments.* Submitted to the Department of Civil and Environmental

Engineering in partial fulfillment of the requirements for the degree of Masters of Science in Civil and Environmental Engineering at the Massachusetts Institute of Technology. May 1995.

- Ayotte, J.D., M.G. Nielsen, G.R. Robinson, Jr., and R.B. Moore. *Relation of Arsenic, Iron, and Manganese in Groundwater to Aquifer Type, Bedrock Lithogeochemistry, and Land Use in the New England Coastal Basins*. United States Geological Survey, Water-Resources Investigations Report 99-4162. 1999.
- Hinkle, S.R. and D.J. Polette, *Arsenic in Groundwater of the Willamette Basin, Oregon, Geochemistry of Arsenic*. United States Geological Survey. Water Resources Investigations Report 98-4205. 1999.
- Ravenscroft, P., J.M. McArthur, and B.A. Hoque, *Geochemical and Paleohydrological Controls on Pollution of Groundwater by Arsenic*. In: *Arsenic Exposure and Health Effects IV*. W.R. Chappell, C.O. Abernathy, and R. Calderon (Eds), Elsevier Science Ltd. 2001.
- Keon, N.E., C.H. Schwartz, D.J. Brabander, C. Harvey, and H.F. Hemond, *Validation of an Arsenic Sequential Extraction Method for Evaluating Mobility in Sediments*. *Environmental Science and Technology*, Volume 35, Number 13, Pages 2778 to 2784, 2001.
- Wilkin, R.T. and R. G. Ford, *Use of Hydrochloric Acid for Determining Solid-Phase Arsenic Partitioning in Sulfidic Sediments*. *Environmental Science and Technology*, Volume 36, Number 22, Pages 4921 to 4927, 2002.
- Wilkin, R.T., D. Wallshlager, and R.G. Ford, *Speciation of Arsenic in Sulfidic Waters*. *Geochemical Transactions*. Volume 4, Number 1, Pages 1 through 7. 2003.
- EPA Research Brief (APM 04-73) - *The Impact of Groundwater-Surface Water Interactions on Contaminant Transport at Contaminated Sites (Draft)*, Prepared by Robert Ford, ORD/NRMRL/GWERD. July 28, 2004.
- P.L. Smedley and D.G. Kinniburgh, British Geological Survey, *Source and Behavior of Arsenic in Natural Waters*. World Health Organization, Water Sanitation and Health website. ([http://www.who.int/water\\_sanitation\\_health/dwq/arsenic/en/](http://www.who.int/water_sanitation_health/dwq/arsenic/en/)) Accessed 2004.

The scope and relevance of each of these documents is summarized below:

### **3.2.1 City of Woburn, Massachusetts, Report on East Side Water Problems – Wells G&H (Dufresne-Henry, 1978)**

Dufresne-Henry (1978) investigated problems with “East Side Well Water” on behalf of the City of Woburn Department of Public Works, particularly complaints of objectionable odors and taste. The Dufresne-Henry investigation was initiated on March 1, 1976.

The report included details of early well history. For example, when the wells were first started, there was evidence of coliform contamination and the State Health Department required that the water be chlorinated. Manganese was also present in the groundwater and the addition of chlorine caused precipitation to occur in the distribution system, leading to stained laundry and associated complaints. The report indicates that excavation of all the organic soil or peat for 30 feet around the wells occurred and replacement with clean, bank-run sand and gravel corrected the coliform contamination. The order to chlorinate was not rescinded, so the wells were not used except in emergencies because of the taste and odor problems. In later years, the increased water demands of the City made it necessary to use wells G and H despite the complaints.

Dufresne-Henry conducted air injection tests using an injection well installed about 30 feet from the gravel packed wells terminating at the same depth, and a series of observation wells. The injections were conducted to improve water quality through aeration. Results indicated that the introduction of air improved the quality of the groundwater, with manganese content dropping from 0.80 mg/L to 0.02 mg/L at a depth of 20 feet, for example based on data from monitoring wells installed near wells G and H as part of the aeration study. Reductions in nitrates were also observed. Implementation of a full-size air injection/diffuser system led to no significant change in water quality at Well G. Nonetheless, the amount of chlorine required to maintain a chlorine residual was noticeably reduced, which Dufresne-Henry identified as a satisfactory result.

Dufresne-Henry noted higher concentrations of iron in Well H compared to Well G, although concentrations of manganese were comparable. Dufresne-Henry suggested the location of Well H in the swamp as a logical explanation. Dufresne-Henry also alluded to the potential presence of organic contamination in wells G and H including “natural substances, insecticides, herbicides, and other agricultural chemicals...” (The high iron concentrations reported by Dufresne-Henry in the summer of 1977 were accompanied by a sulfide smell, which would accompany reducing groundwater.)

Dufresne-Henry determined that the odor complaints were attributable to the action of chlorine on organic matter residing in the distribution system. Samples of raw water taken directly from municipal wells G and H had no objectionable odors. Dufresne-Henry noted that manganese is present in the groundwater at wells G and H at a concentration of 0.6 milligrams per liter (mg/L) and advised that the Massachusetts Department of Environmental Quality Engineering (now the Department of Environmental Protection) would like to have the manganese removed “to a more acceptable level of 0.05 mg/L.” Dufresne-Henry recommended the construction of a treatment plant (\$1.5 million estimated) and the installation of a gravel packed well between G and H “so that the full capacity of the groundwater resource which exists in the Aberjona River Valley can be utilized.”

### **3.2.2 *Arsenic Species as an Indicator of Redox Conditions in Groundwater*** **(Cherry et al, 1979)**

Cherry et al (1979) identified the potential for arsenic species distributions in natural water to serve as a proxy redox indicator, particularly in groundwater, which is characterized by long equilibration time and a favorable pH-redox domain. Cherry et al cite the redox transformations

of arsenic species as sufficiently slow to enable sample collection and laboratory analysis before excessive change in species distribution, but sufficiently rapid for arsenic species to adjust to the dominant redox condition of the water. Arsenite/arsenate ratios change over a period of days, rather than seconds or minutes. Cherry et al mentioned the potential interferences of sulfide sequestration on arsenic concentrations, but noted that ferrous iron (Fe[II]) activity would limit sulfide activity such that arsenic sulfide would not reach saturation. However, Cherry et al stated that in some situations, dissolved arsenic concentrations would be limited by adsorption.

### ***3.2.3 Adsorption of Arsenite and Arsenate on Amorphous Iron Hydroxide (Pierce and Moore, 1982)***

Pierce and Moore (1982) illustrate one of the main factors controlling arsenic in natural aquatic systems: adsorption on sediments. The dependency of arsenic adsorption on concentration, amount of sorptive oxides, pH, and the oxidation state of arsenic is addressed. Amorphous iron hydroxide, which has a universal presence in clays, soils and sediments, possesses significant adsorptive properties and plays a significant role in arsenic adsorption. The extremely high adsorptive capacity of amorphous iron hydroxide for arsenic is explained by a loose, highly hydrated structure that allows ions to readily diffuse through the structure, and therefore does not limit adsorption to external surfaces as with more crystalline solids. Pierce and Moore also explain that the adsorption of arsenic to amorphous iron hydroxide indicates a specific adsorption or formation of chemical bonds between arsenic species and the adsorbent, rather than the very rapid electrostatic attraction; thus, identifying a kinetic element in the adsorption process.

### ***3.2.4 Fixation, Transformation, and Mobilization of Arsenic in Sediments (Brannon and Patrick, 1987)***

Brannon and Patrick (1987) studied the fixation, speciation, and mobilization of arsenic in sediment during sediment/water interactions, with an emphasis on the following:

- Transformation and fixation of As(V) in anaerobic sediment;
- Long-term (6-month) release from sediment of naturally occurring and added arsenic; and
- Sediment properties affecting mobilization of As(V), As(III), and organic arsenic.

Brannon and Patrick reported results from studies with dredged sediments from a variety of fresh and salt water harbor environments that included ten locations in Indiana, Wisconsin, Michigan, California, Connecticut, Texas and Washington State. Brannon and Patrick found that arsenic could be mobilized over both the short and long term. Short-term releases were found to be related to arsenic concentrations in the interstitial water and exchangeable phases of the sediment. Long-term net mass releases were related to total and extractable iron, and the calcium carbonate (CaCO<sub>3</sub>) equivalent concentration. Redox potential and pH also played a significant role in the transformation of arsenic.

Testing involved, in part, the addition of arsenic to sediments. Under oxidizing conditions, a maximum of 17.1-percent of added arsenic remained in solution compared to a maximum of

69.5-percent under reduced conditions, with As(III) constituting all the soluble arsenic under anaerobic conditions at pH 5 to 6.5. Under conditions where anaerobic sediment is in intimate contact with anaerobic water, releases of As(III) to the water should occur. When anaerobic sediments (freshwater and saline environments) were subject to short term mixing, such as during hydraulic dredging operations or propeller wash from passing ships, As(III) was the major arsenic species released. However, leaching experiments indicated that releases of arsenic will persist for at least six months (the longest period tested) under agitated, aerobic conditions.

The release of arsenic species was phased during aerobic leaching conditions, with As(III) predominating initially (first 1 to 2 months) and As(V) becoming the predominant species as leaching progressed. Simulation of situations where anaerobic and aerobic conditions may alternate, such as in areas subject to periodic inundation, showed almost the exclusive release of As(V). These results indicated that releases of the more toxic As(III) could be curtailed by alternating anaerobic and aerobic conditions. [This alternation of aerobic and anaerobic conditions is consistent with conditions in the wetland and upper peat layers at Wells G and H, where the degree of wetland peat layer inundation varies with meteorologic conditions, river stage, and the influence of water supply well withdrawals.]

Brannon and Patrick also noted that iron oxides and hydroxides strongly adsorb arsenic compounds, and that iron and aluminum have been demonstrated to be major sinks of added arsenic in aerobic soils. Increases in arsenic concentrations in the moderately reducible phase extractant were paralleled by increased iron concentrations in the moderately reducible phase extractant. This indicated that arsenic shifts to more immobile phases during aerobic leaching, thus considerably reducing the mobility of sediment-borne arsenic and the potential for dissolved phase arsenic release.

### ***3.2.5 Partitioning of Arsenic and Metals in Reducing Sulfidic Sediments (Moore et al, 1988)***

Moore et al (1988) explored the partitioning behavior of arsenic, copper, and zinc in sediment of a Montana reservoir, which was identified as a source of contamination in an adjacent alluvial aquifer. In this study, arsenic transferred to groundwater by formation of diagenetic sulfides in sediment. This study identified a redox interface in the sediments that controlled the partitioning of arsenic and other metals. Pore water concentrations of arsenic, copper and zinc were controlled by the solubility of iron and manganese oxyhydroxides in the oxidized zone and by metal sulfides in the reduced zone. Metal concentrations (Fe, Mn, As) increased as oxyhydroxides dissolved in the reduced zone. Diagenetic sulfides scavenged these elements resulting in enrichment relative to surface (shallower) sediments. Consumption of dissolved oxygen and precipitation of sulfide altered oxidation states of trace elements in pore water and sediment and, for example, reduced As (V) to the more toxic As(III). Chemolithic bacteria mediated the reactions. Moore et al noted that 1-percent carbon was sufficient to drive bacterial reduction and increase the rate of sulfide reactions. In this scenario, trace elements stored by formation of authigenic sulfides were a potential source of secondary contamination if sulfides were moved into oxidizing environments where they are unstable. Chemolithotrophic bacteria assisted in this sulfide oxidation process.

### **3.2.6 *Arsenic and Selenium Chemistry as Affected by Sediment Redox Potential and pH (Masscheleyn et al, 1991a)***

Masscheleyn et al (1991a) identified redox conditions that can limit or enhance the translocation and movement of arsenic and selenium in the sediment-water environment. Redox potential and pH affect both speciation and solubility of arsenic and selenium in reservoir sediments. Under highly oxidized conditions, arsenic solubility was low and most arsenic in solution was arsenate, As(V). Upon reduction, As(III) became the major arsenic species in solution and arsenic solubility increased substantially. The data suggest that the increase in soluble arsenic was due to reductive dissolution of iron oxyhydroxides, which strongly adsorb As(V). Arsenic solubility increased 25 times upon reduction from a redox potential of 500 millivolts (mV) to -200 mV. More than half the arsenic present in sediment was soluble at -200 mV. Masscheleyn et al noted that precipitation/dissolution reactions of arsenic minerals were not the controlling factors in arsenic solubility; rather, arsenic chemistry is controlled by adsorption-desorption mechanisms. Also, total water-soluble arsenic and iron were highly correlated, while there was no correlation between aluminum and manganese, suggesting that aluminum and manganese oxides are less important in controlling arsenic solubility.

### **3.2.7 *Effect of Redox Potential and pH on Arsenic Speciation and Solubility in a Contaminated Soil (Masscheleyn et al, 1991b)***

Masscheleyn et al (1991b) investigated the control of redox and pH on arsenic speciation and solubility and explored arsenic behavior over a range of redox and pH conditions. For example, under moderately reducing conditions (0 to -100 mV), arsenic solubility was controlled by the dissolution of iron oxyhydroxides. Arsenic can be co-precipitated as As(V) with iron oxyhydroxides and subsequently released upon their solubilization under reducing conditions. Masscheleyn et al observed slow kinetics for the As(V) -As(III) transformations, which can explain, for example, why thermodynamically unstable As(V) species can be observed under reducing conditions. Nonetheless, Masscheleyn et al advised that high redox and non-alkaline conditions minimize solubility and mobilization of arsenic.

### **3.2.8 *The Distribution and Depositional History of Metals in Surface Sediments of the Aberjona River Watershed (Knox, 1991)***

Knox (1991) studied the transport of primarily arsenic and associated water quality parameters in the Mystic Lake Upper Forebay in Winchester, Massachusetts during the period from June 1995 to July 1996. Sediment and surface water were sampled for a variety of chemical constituents. Through radiological dating, the sedimentation rate was determined to be approximately 0.42 to 0.6 centimeters per year in the upper forebay. Sampling was conducted during average base flow conditions and during storm events. Knox noted that during the summer suspended solids and arsenic levels were higher in the outflow from the forebay in comparison to the inflow. This led to the theory that the higher suspended solids may be due to plant matter and the high arsenic concentrations may be due to arsenic attached to plant matter, arsenic released by plant metabolism activity, or due to groundwater influx containing elevated arsenic levels. In the winter there was a reduction in suspended solids and arsenic in the discharge. During storm events more arsenic was attached to the larger suspended sediments (>8 microns) than present in



smaller particulates (between 0.45 and 8 microns). During high flow events there were two distinct arsenic loading pulses. The first pulse was due to drainage from the more southerly Winchester sub-basin and the second pulse was from the upper portions of the basin Woburn-Central and Woburn-North areas and, in particular, the HBHA. Knox referred to the first pulse as the quick storm response and the later pulse as the slow storm response, and calculated that the first and second pulses were responsible for discharging about 5.7 pounds and 7.5 pounds of total arsenic to the Upper Forebay during a January storm. The second pulse had more dissolved arsenic and the particulates were smaller in comparison to the first pulse. Based on a range of sediment arsenic data, the rate of arsenic burial in forebay sediments was between 25 and 93 pounds per year. Over the course of a year, the amount of dissolved and particulate arsenic entering the Forebay appeared to be about equal. The amount of particulates accumulating in the Forebay was about 65-percent. The amount of arsenic entering the Forebay on an annual basis was approximately 34 to 153 pounds per year. Solo-Gabriele (1995) showed yearly, average, arsenic releases to the Aberjona watershed of 600 pounds per year for the period from 1900 to 1993. The highest fluxes were observed in the 1920s, 1950s and 1960s.

### **3.2.9 Arsenic in the Aberjona Watershed (Aurilio, 1992)**

Aurilio (1992) examined the source, distribution, and speciation of arsenic in the Aberjona River watershed, with a focus on the HBHA and the Upper and Lower Mystic Lakes. Aurilio estimated that 300 metric tons of arsenic were present in the contaminated areas of the watershed, and used manufacturing data relevant for the period of sulfuric acid, arsenical pesticide, leather, glue, and gelatin manufacturing in the Aberjona River valley to conclude that 200 to 700 metric tons of arsenic may have been released as a result of these activities. Approximately 10 metric tons migrated over 10 kilometers from the site of origin. The largest quantity of arsenical waste is attributable to sulfuric acid manufacturing, followed by arsenical pesticide manufacturing, which took place at the Industri-Plex Site. Pyrite ores used in acid manufacturing contained arsenic and other metals as impurities.

Aurilio described the complex geochemistry of arsenic, noting that the two most prevalent arsenic species found within the pH range of natural waters are arsenite ( $\text{As}[\text{III}]$ ), which is thermodynamically favored in acidic and anoxic waters, and arsenate ( $\text{As}[\text{V}]$ ), which is prevalent in oxic waters. Reduction and methylation of arsenic (arsenite, dimethylarsenate, monomethylarsenate) may lead to increased mobilization of arsenic, since these forms are much less particle reactive than arsenate. Oxidation of arsenic to arsenate ( $\text{As}[\text{V}]$ ) and adsorptive scavenging by iron oxides exerts significant control on arsenic solubility under oxidizing conditions.

Aurilio reviewed the complex factors controlling the fate of arsenic in the HBHA and the Upper and Lower Mystic Lakes, noting that arsenic speciation does not always correspond to purely thermodynamic considerations. Aurilio encountered and described diverse chemical, physical, and biological controls on the mobility of arsenic.

### ***3.2.10 Characterization of the Physical and Engineering Properties of the Aberjona Wetland Sediments (Bialon, 1995)***

Bialon (1995) conducted a study of the controlling mechanisms of the hydraulic properties of the Aberjona wetland sediment as a Masters Thesis at the Massachusetts Institute of Technology. The study was based on the results of 35 constant rate of strain consolidation (CRSC) tests, 2 cylindrical specimen triaxial-cell permeameter tests, and 4 cubical specimen triaxial-cell permeameter tests. Specimens were sampled from three locations within the Aberjona wetland by a manually operated fixed-piston sampler. The work was conducted in the wetland to the northwest and west of Well H near the Aberjona River.

Bialon observed that the wetland sediment was divided into five distinctive layers based primarily on a visual classification: live root mat, a typha peat layer, sedge peat layer, read woody peat layer, and the diatomaceous earth layer. A range of properties was presented for each of the layers.

The range of compressibility ratios was very comparable between the wetland layers. Bialon found that the Compressibility Ratio (CR) and the Recompression Ratio (RR) of the peat layer ranged from (0.275 to 0.980) and (0.013 to 0.096), respectively. Bialon noted that the compressibility properties were much lower in the diatomaceous earth, with the values of CR and RR of (0.224 to 0.412) and (0.002 and 0.016), respectively.

Bialon concluded that there appeared to be no significant difference in hydraulic conductivity between the wetland layers and that the range of in-situ hydraulic conductivity throughout the wetland layers is between  $2.0\text{E-}6$  centimeters per second (cm/sec) and  $6.0\text{E-}4$  cm/sec. Study results suggested that the in situ hydraulic conductivity of the wetland layers was not related to void ratio. Bialon noted that organically bound pore water influenced the variability in hydraulic conductivity and found that the amount of bound pore water increased with increases in the organic content of sediments.

### ***3.2.11 Relation of Arsenic, Iron, and Manganese in Groundwater to Aquifer Type, Bedrock Lithogeochemistry, and Land Use in the New England Coastal Basins (Ayotte et al, 1999)***

The Ayotte et al (1999) USGS study examined arsenic, iron and manganese data from public water supply wells in the New England Coastal Basin and determined that the concentration of arsenic in bedrock groundwater varies with bedrock lithology, but also with land use (i.e., higher in agricultural areas due to the use of arsenical pesticides). Ayotte et al found the lithogeochemical relation to be statistically stronger than the land use relation, but also acknowledged the bias in their data set to public water supply wells. Non-potable groundwaters (those with high dissolved solids or with water that does not meet regulatory standards) could differ with respect to spatial and chemical association. Nonetheless, Ayotte et al (1979) found that arsenic was detected in 25.5-percent of public supply wells in bedrock and in 7.6-percent of stratified drift aquifers, noting that the significant difference may result from the more evolved chemistry of bedrock aquifers (longer residence time). Groundwater residence time in stratified drift aquifers was relatively short and more readily subject to recharge from the surface. Ayotte

et al found that high iron and manganese concentrations were not always a good indicator of high arsenic concentrations in the bedrock supply wells, suggesting that simple dissolution of iron sulfides and hydroxides did not account for arsenic concentrations in bedrock groundwater.

### ***3.2.12 Arsenic in Groundwater of the Willamette Basin, Oregon – Geochemistry of Arsenic (Hinkle and Polette, 1999)***

Hinkle and Polette (1999) conducted a study as part of the USGS in 1996 designed to increase the current understanding of the groundwater resource, and to better characterize the distribution of naturally occurring poor quality groundwater in the Willamette Basin, Oregon, in response to increasing demands on groundwater resources. Arsenic concentrations exceeding the then current EPA MCL of 50 ug/L are widespread in groundwater in the Willamette Basin.

Hinkle and Polette described factors controlling the distribution of arsenic in groundwater such as arsenic sources and processes controlling arsenic mobility. Processes that have been shown to control arsenic mobility in natural systems were discussed. Arsenic speciation data collected as part of this project, along with some historical speciation data, were presented. Finally, geochemical data (including the speciation data) and information from existing interpretive reports were used to construct preliminary hypotheses regarding possible geochemical controls over mobilization of arsenic in the Willamette Basin.

Hinkle and Polette described two categories of processes that largely control arsenic mobility in aquifers: (1) adsorption and desorption reactions and (2) solid-phase precipitation and dissolution reactions. Arsenic adsorption and desorption reactions are influenced by changes in pH, occurrence of redox (reduction/oxidation) reactions, presence of competing anions, and solid-phase structural changes at the atomic level. Solid-phase precipitation and dissolution reactions are controlled by solution chemistry, including pH, redox state, and chemical composition. Existing data, including the speciation data, and published interpretations were used to establish preliminary hypotheses for the evolution of high-arsenic groundwater in the Willamette Basin.

### ***3.2.13 Geochemical and Paleohydrological Controls on Pollution of Groundwater by Arsenic (Ravenscroft et al, 2001)***

Ravenscroft et al (2001) examined the occurrence of arsenic in groundwater in the Bengal Basin of Bangladesh and West Bengal (India), where they identify the reduction of iron oxyhydroxide (FeOOH) and the release of its sorbed arsenic load to solution as an important mechanism by which groundwater world wide becomes polluted with arsenic. Ravenscroft et al assigned an important role to organic matter, in particular peaty sediments, in generating anoxic conditions in groundwater, identifying peat as the redox driver for reduction of FeOOH. The distribution of pollution by arsenic reflects the distribution of buried peat deposits. Ravenscroft et al postulated that the pollutant arsenic in groundwater occurs where microbial reduction of FeOOH has released sorbed arsenic and also reduces the arsenic. Organic matter is required to drive this process. They further postulated that the distribution of organic matter in the aquifer sediments was the main control on the distribution of arsenic pollution in their study area. They also found that poor correlations of arsenic with iron may arise because of re-sorption (partial, since arsenite

adsorbs less well than does arsenate) of arsenic on to freshly exposed FeOOH surfaces exposed by dissolution or because the arsenic/FeOOH ratio may vary from place to place in response to differing amounts of FeOOH and mineral surface, and differing mineral abundances.

#### ***3.2.14 Validation of Arsenic Sequential Extraction Method for Evaluating Mobility in Sediments (Keon et al, 2001)***

Arsenic mobility and transport in the environment are strongly influenced by the association of arsenic with solid phases in soil and sediment. Keon et al (2001) tested a sequential extraction procedure intended to differentiate the following pools of solid phase arsenic: loosely and strongly adsorbed arsenic; arsenic coprecipitated with metal oxides or amorphous monosulfides; arsenic coprecipitated with crystalline iron (oxyhydr)-oxides; arsenic oxides; arsenic coprecipitated with pyrite; and arsenic sulfides. Additions of arsenic-bearing phases to wetland and riverbed sediment subsamples were quantitatively recovered by a sequential extraction procedure.

Wet sediment subsamples from both highly contaminated wetland peat and less arsenic-rich sandy riverbed sediment from Wells G and H were used to test the extraction procedure. The proportional distribution of arsenic among extractant pools was consistent for subsamples of the wetland and for subsamples of the riverbed sediments.

#### ***3.2.15 Use of Hydrochloric Acid for Determining Solid-Phase Arsenic Partitioning in Sulfidic Sediments (Wilkin and Ford, 2002)***

Wilkin and Ford (2002) examined the use of room-temperature hydrochloric acid and salt solutions of magnesium chloride, sodium carbonate, and sodium sulfide for the removal of arsenic from synthetic iron monosulfides and contaminated sediments containing acid-soluble arsenic reacts with hydrogen sulfide released from Acid Volatile Sulfide (AVS) phases and precipitates at low pH as disordered orpiment or alacranite.

Arsenic sulfide precipitation is consistent with geochemical modeling in that conditions during acid extraction are predicted to be oversaturated with respect to orpiment, realgar, or both. Wilkin and Ford found that acid extraction of arsenic from sulfide-bearing sediments will give biased results that overestimate the stability or underestimate the bioavailability of sediment-bound arsenic. Alkaline solutions of sodium sulfide and sodium carbonate are efficient in removing arsenic from arsenic sulfides and mixed iron. Arsenic sulfides are more efficiently removed because of the high solubility of arsenic at alkaline pH, the formation of stable arsenic complexes with sulfide or carbonate, or both.

#### ***3.2.16 Speciation of Arsenic in Sulfidic Waters (Wilkin et al, 2003)***

Wilkin et al (2003) examined the change in As(III) speciation from arsenite to a distribution of arsenic-sulfide complexes (thioarsenic species) with increase sulfide concentrations in aqueous solution. Conversion from neutral arsenate species  $[\text{As}(\text{OH}_3)^0]$  to anionic thioarsenite species may regulate the transport and fate of arsenic in sulfate-reducing environments by governing sorption and mineral precipitation reactions. However, concentrations of dissolved sulfide are

typically low when reactive iron is abundant. Dissolved sulfide concentrations are able to increase only after supply of reactive iron is exhausted via reductive dissolution processes and subsequent iron monosulfide precipitation. The presence of reactive iron will generally preclude the formation of thioarsenic species in sulfate-reducing systems. Environments where the abundance of reactive iron is limited will favor sulfide accumulation and thioarsenite formation.

### ***3.2.17 The Impact of Groundwater-Surface Water Interactions on Contaminant Transport at Contaminated Sites – Draft (Ford, 2004a)***

Ford (2004a) studied the impact of groundwater-surface water interactions on contaminant transport in the HBHA at the Industri-Plex Superfund Site. Ford's site monitoring strategy included the installation of tubing wells, diffusion samplers, and depth-resolved sampling within the pond to measure water chemistry within the HBHA and sampling of upgradient groundwater wells.

Ford determined that in addition to the arsenic that was flowing into the pond through groundwater discharge that "a key component that contributes to the arsenic mass balance within the (pond) water column is the internal recycling of arsenic originally derived from ground-water discharge. The internal recycling process is due to the coupling of iron oxidation-reduction processes that, in part, control the distribution of arsenic between water and solids within the water column." Ford found that arsenic enters the pond through groundwater and upon entering the pond some arsenic partitions to sediment and some contributes directly to surface water contamination. However, the amount that partitions to the sediments can reenter the water column under reducing conditions. Ford observed that this occurred following a large storm event, and postulated that arsenic contaminated sediment from the aerobic zone had been re-deposited within the pool and subjected to reducing conditions. In this particular case, the concentration of arsenic in pond water was approximately equally associated with groundwater flux and sediment releases. Ford noted that the removal of the contaminated groundwater source might not result in full cleanup of the HBHA water.

Ford (2004a) also conducted a literature search and echoed the following themes reported by the collective authors:

- Hydrologic transients imposed by long-term (seasonal) and short-term (storm events) flow variations impact the types and intensity of chemical reactions that influence contaminant chemical speciation and transport;
- Microbial degradation of natural and anthropogenic sources of organic matter and the availability of terminal electron acceptors influences the distribution of oxidation/reduction (redox) zones within the groundwater/surface water (GW/SW) transition zone;
- Microbial processes and contaminant transport are dependent on the chemical characteristics of both the liquid and solid phase across the GW/SW transition zone; and

- Chemical gradients of major and trace elements/contaminants are often greatest in the vicinity of the GW/SW transition zone.

### **3.2.18 Source and Behavior of Arsenic in Natural Waters (*Smedley and Kinniburgh, 2004*)**

Smedley and Kinniburgh (2004) prepared a comprehensive review of arsenic sources and behavior in natural waters, and address topics such as mineral-water interactions, groundwater environments showing enhanced arsenic concentrations, and common features of groundwater arsenic problem areas. The discussion of arsenic geochemistry is current and provides and identifies outstanding questions and further needs.

## **4.0 SITE PHYSICAL CHARACTERIZATION**

The Wells G and H Superfund Site is a 330-acre site situated in east Woburn, Massachusetts. The site is bounded by Route 128/Interstate 95 to the north, Interstate 93 to the east, Boston & Maine railroad tracks to the west, and Salem and Cedar Streets to the south (see Figure 1). Wells G and H are two municipal water supply wells located in the Aberjona River Valley that supplemented the City of Woburn's water supply in the 1960s and 1970s (EPA, 1989).

### **4.1 Contamination Synopsis**

#### **4.1.1 Operable Units**

The OU-1 Source Area properties consist of the W.R. Grace & Company (Grace), UniFirst Corporation (UniFirst), New England Plastics (NEP), Wildwood Conservation Corporation (Wildwood), and Olympia Nominee Trust (Olympia) properties, the locations of which are depicted on Figure 1 (EPA, 2004).

The Central Area (OU-2) consists of all groundwater and land within the area defined as the Wells G and H Superfund Site, excluding the areas defined for Source Area (OU-1) properties and the Aberjona River Study (OU-3).

The groundwater aquifer underlying the Site is not currently used as a municipal drinking water source. The objectives listed in the Site ROD include restoring the aquifer to drinking water standards. Public opinion has been opposed to utilizing Wells G and H for water supply. However, the City of Woburn has expressed interest in having the source available for future use (MADEP, 2004). The MADEP's Groundwater Use and Value Determination assigned a "medium" use and value for the Site aquifer, based on a balanced consideration of several factors, and contemplates future use of the aquifer for domestic and industrial purposes (EPA, 2004).

The portion of the Central Area (OU-2) known as the Southwest Properties includes the Aberjona Auto Parts, Whitney Barrel, and Murphy Waste Oil properties. Aberjona Auto Parts began operations in the mid-1950s for the sale and reconditioning of used and wrecked automobiles, and was also a gasoline service station. Current uses of the Aberjona Autoparts property include the remnants of the now closed auto salvage operation, vehicle repair, landscaping, and a detached residence. The Whitney Barrel Company located on Salem Street commenced operations in 1949, and reconditioned drums, boilers, tanks and machinery. Current uses of the Whitney Barrel property are mixed and include landscaping firms, automotive glass repair, and miscellaneous storage. The Murphy Waste Oil property is a Resource Conservation and Recovery Act (RCRA)-permitted Treatment, Storage and Disposal Facility (TSDF) operated by Clean Harbors, Inc. (EPA, 2004).

The Aberjona River Study (OU-3) area consists of the Aberjona River and its tributaries, sediments, and associated 38-acre wetland area that lie within the 330-acres of the Site. The Aberjona River begins in Reading, Massachusetts, and flows through the Industri-Plex Superfund Site to the north of Route 128 before flowing through the Site, and eventually reaches

the Mystic Lakes in Winchester. The investigation of the Aberjona River was recently merged with the Industri-Plex Superfund Site and the Aberjona River study area now extends to the Mystic Lakes in Winchester.

#### ***4.1.2 History of Contamination***

On May 4, 1979, 184 55-gallon drums containing polyurethane and toluene diisocyanate were found on Mishawum Road on a vacant lot owned by the Massachusetts Bay Transportation Authority (MBTA). The drums were removed during negotiations with the Massachusetts Department of Environmental Quality Engineering (DEQE) (now the MADEP). The drum discovery prompted the DEQE to sample the nearest downgradient public water supply, Wells G and H. Several chlorinated VOCs were detected in water from Wells G and H at concentrations ranging from 1 to 400 ug/L. The City of Woburn was forced to use Metropolitan District Commission (MDC) water to supplement its public water supply when Wells G and H were shut down on May 21, 1979. The MDC (now the Massachusetts Water Resources Authority or MWRA) continues to supplement the City of Woburn's water supply (EPA, 2004).

EPA and various property owners have conducted numerous studies to determine the nature and extent of contamination at the Site. The following five facilities have been identified as sources of contamination – Grace, UniFirst, NEP, Wildwood, and Olympia. Wells G and H Superfund Site was listed as a Superfund Site on the National Priorities List (NPL) on December 21, 1982 (EPA, 2004).

#### ***4.1.3 Contaminant Summary***

The following summarizes the contaminants detected at the Site as identified in the ROD (EPA, 2004).

**Groundwater.** Chlorinated VOCs are the primary groundwater contaminants. Groundwater contamination has been found in overburden and bedrock aquifers at the Grace, UniFirst, Wildwood and NEP properties as well as the Central Area (OU-2) of the Site. Groundwater contamination has been found in the overburden aquifer at the Olympia FDFA.

The Grace contamination consists primarily of chlorinated solvents characterized by a high percentage of trichloroethene (TCE) and 1,2-dichloroethene (DCE). Other contaminants include PCE and vinyl chloride. The UniFirst contamination is predominantly PCE. Secondary constituents are 1,1,1-trichloroethane (1,1,1-TCA), and smaller amounts of TCE and 1,2-DCE. The Wildwood contamination consists primarily of TCE detected at a number of wells, with 1,1,1-TCA, 1,2-dichloroethene (DCE), and PCE detected at a few locations. At Olympia, TCE and xylene were detected in the overburden. At NEP, PCE, TCE, 1,1,1-TCA and 1,2-DCE were found in bedrock and overburden wells.

**Soil.** Chlorinated VOCs are the primary contaminants in soil and were found at various levels on the Wildwood, Olympia, Grace, NEP and UniFirst properties. Some chlorinated VOC soil contamination was also found in a wetland area at Wildwood.



Other soil contaminants include PCBs, chlordane, phthalates, and polyaromatic hydrocarbons (PAHs), which were found dispersed throughout the Wildwood property. PAHs were found in one location at Olympia. Phthalates were found in a small area at NEP. Assorted debris and sludge contaminated with lead, VOCs, PAHs, and pesticides were also found at Wildwood.

**Sediment/River.** Aberjona River and wetland sediments were contaminated with PAHs, PCBs, pesticides, and metals such as arsenic, copper, mercury, zinc, and chromium. Surface water samples revealed low levels of chlorinated VOCs. Metals and phthalates were also noted in surface water.

**Air.** Air monitoring, conducted during all site investigations, did not reveal any VOC readings above background at the breathing zone.

Potential health risks identified at the Site include ingestion of contaminated groundwater, inhalation of volatiles while showering, and dermal contact or incidental ingestion of surface soils (EPA, 1989). Arsenic in sediment was identified as contributing to risk above a level of concern for recreational site use. For ecological receptors, the evaluation indicated potential risk to aquatic life due to metals and phthalates in surface water. Potential risk to invertebrates and mammals were identified due to metals, pesticides, PAHs, and PCBs in sediments (EPA, 2004).

## **4.2 Aberjona River**

The Aberjona River headwaters are in west-central Reading, Massachusetts. The River flows southwest from Reading through the City of Woburn and the Town of Winchester before entering the Mystic Lakes system. The Aberjona River passes through a mix of parkland, residential, urban, and light industrial areas, with the industrial areas found largely in the City of Woburn. Consequently, the river and associated water bodies and wetlands are affected by a number of potential factors, including neglect, indiscriminant disposal of debris, local and upstream runoff, including non-point and point source discharges. Development, loss of flood storage, culverting, and channelization has also impacted the river (M&E, 2003).

In 1985, the USGS conducted a 30-day aquifer pump test to determine the zone of contribution to Wells G and H (USGS, 1987). The study concluded that a hydraulic connection between the aquifer and the river exists under pumping conditions. Also in 1985, EPA determined the extent and type of wetlands that exist at the study area (PRC, 1986)

Massachusetts regulations classify the Aberjona River as Class B surface water that supports fish populations. Fish sampling confirmed the presence of warm water species throughout the study area. Class B waters are defined by the MADEP as “a habitat for fish, other aquatic life and wildlife, and for primary and secondary recreation. Where designated they shall be suitable as a source of public water supply with appropriate treatment. They shall be suitable for irrigation and other agricultural uses and for compatible industrial cooling and process uses. These waters shall have consistently good aesthetic value.” “Primary contact recreation” represents “any recreation or other water use in which there is prolonged and intimate contact with water and a significant risk of ingestion. These include, but are not limited to, wading, swimming, diving, surfing and water skiing.” “Secondary contact recreation” represents “any recreation or other

water use in which contact with water is either incidental or accidental. These include but are not limited to fishing, boating, and limited contact incidental to shoreline activities.” (MADEP, 1996 and 1997)

In slow-moving sections, the river meanders through vegetated wetlands (HBHA north of Route 128 and the Wells G and H 38 acre wetland in Woburn). In some of the more urban areas (Route 128 area and in downtown Winchester), the river is culverted or artificially channeled (M&E, 2003).

The population has grown in recent years in the City of Woburn from 35,835 in 1990 to 37,528 in 2000 (M&E, 2004) and from 21,221 in 1990 to 21,344 in 2000 in the Town of Winchester (M&E, 2004) with the expansion of light and technology-related industries along the major interstate highways (Routes 93 and 95/128). The overall increase in population and development has placed an additional demand on the use of open space areas, particularly on the parklands bordering the river in the area of the Woburn-Winchester town line and along the lower reaches of the Aberjona River as it enters the Upper Mystic Lake. Future land use is not expected to change significantly (M&E, 2004).

Wildlife habitat associated with the river and water bodies within the study area is generally restricted to a relatively narrow corridor. The width of this corridor varies from approximately 20 feet to 0.3 miles. At several locations, development encroaches to the waters edge. Habitats along the river include emergent, scrub/shrub and forested wetlands, fragmented upland forests, sub-mature woodlots, grassy meadows, and maintained parkland. The study area is in an urban watershed. In areas not directly impacted by human activities through alterations of the riverbank or channelization, the river habitat is indirectly influenced by stormwater run-off or proximity to human activity, which can affect habitat quality for some species (M&E, 2004).